A STUDY OF THINKING*

By ROBERT OPPENHEIMER

In the spring of 1949, the Massachusetts Institute of Technology held a convocation devoted to the celebration of recent successes in the sciences, and to reflections on their portent. Mr. Churchill, then Prime Minister of the United Kingdom, commented in the course of his address, "The Dean of the Humanities spoke with awe, 'of an approaching scientific ability to control men's thoughts with precision.' I shall be very content to be dead when that happens." This book which is before us need lend no haste to Churchill's thoughts of death, nor to those of the many others who, without words or with words of less austere finality, share his anxieties.

Even the lay reader will recognize in this book some fresh and solid steps toward an understanding of characteristic traits of man's rational behavior. He will also see that the psychological sciences have a very long way indeed to go. For *A Study of Thinking* has in many ways the flavor of the opening of a new science. This is not because its authors so regard themselves. They are learned in the literature of their science; they make discriminating and frequent use of the findings of those who have worked in the study of perception, of concept formation, of linguistics and of learning. They are happy to recognize that the logical ideas to which they are led are as well explicated by Aristotle as ever since; it is clear that the models of von Neumann and the theory of games have contributed both to their explicit terminology, and to their ways of thinking and of formulating problems.

But the book has a unity of view and a fervor of conviction which makes it point to the future. If it raises more questions than it answers, the questions are new and newly sharp because there are some answers in the book. Although there is little in the findings here reported that shocks or transcends common sense, these findings are cast with the precision and objectivity which is indeed the mark of a science finding its bearings.

We are concerned throughout with the discovery and creation of order in man's cognitive life. We are dealing with a work which both

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studies a part of this great theme and, in itself, exemplifies it. The theme is vast. Man has a great capacity for discrimination. His potential sense of otherness is almost unlimited. Rational life begins with the selective practice of ignoring differences, failing in truth to perceive them; rational life begins with the failure to use discriminatory power in anything like its full potentiality. It lies in the selection, arrangement, and appropriate adequation to the objects of perception and thought, of limited traits, of a small residue of potential wealth.

Dr. Brown in his Appendix assaults the analogous problems of language, language made possible only because so many differences of sound and tone, aspiration, and articulation are ignored in the forging of a common tongue. Lest this creation of order from chaos be seen wholly as attrition, one anticipatory finding: the powers of discrimination which are subordinated in learning and in language, are not lost; they are in a sense set to one side, or on the back burner. They do not come easily and immediately into use; but once there is evidence that they are relevant to the subject of learning or thought, they can be brought back. Thus we can learn languages whose phonetic and sonic distinctions differ in profound ways from those of our own; thus it is that we can not only see the world as ordered, but can learn when we have missed the point, and can attain new levels of insight, complexity, richness and structure.

A physicist, reflecting on these matters, is likely to be reminded of his experiences with the quantum theory. In perception, in learning concepts, only a small part of our potential perceptivity is engaged. The small part, if we are to be successful, must have a proper adequation to our theme. The rest cannot be involved in the operation if there is to be clarity or order at all. Some of the rest will be involved in other problems and other contexts. These limited constellations of our human powers are used in a complementary way, none of them exhausting what we could do, but each in a measure excluding the concurrent use of all the others. In physics we have learned that in experiments on an atomic scale, one experimental arrangement and the words and ideas appropriate for describing the findings of that experiment, are complementary to others which might indeed have been used, which will again be used, but which cannot be used concurrently.

What then is this book all about? Certainly not about the whole of perception and of thinking; certainly not even about the whole of the

processes of abstraction and categorization. But the authors tell us in their preface,

> This book is an effort to deal with one of the simplest and most ubiquitous phenomena of cognition: categorizing or conceptualizing. On closer inspection, it is not so simple. The spirit of the inquiry is descriptive. We have not sought "explanation" in terms of learning theory, information theory, or personality theory. We have sought to describe and in a small measure to explain what happens when an intelligent human being seeks to sort the environment into significant classes of events so that he may end by treating discriminably different things as equivalents. In dealing with the problem, we have found ourselves travelling far afield.

More specifically, the book is an extended analysis, and a report of experiments, some done earlier by these and other scientists, but the majority done for testing the analysis and answering the questions which it raises. It deals with situations neecessarily almost ludicrously abstract and unlifelike, with how people learn to categorize, with how they learn to recognize instances that they see or hear as belonging or not belonging to a class, as illustrating or not illustrating a concept. It asks by what procedures people learn to do these things. Are they procedures which show a certain consistency of logical method? Do the various steps in learning form a coherent pattern, or is each step a more or less random probe? Can one perceive the logical structure underlying the effort of learning? Can one describe it as a strategy of learning? And to the extent to which the answers of these questions are affirmative, can one understand the choice of strategy in terms of its difficulty, its economy, its certitude, its abstractness, the burden it puts on memory and inference? How is the choice of strategy affected by the circumstances of the learning process, the pressure of time, the availability of confirmation, the penalties attaching to error, the purity or allusiveness of the material being ordered?

In short, this is an inquiry, limited to the most antiseptic, controllable and gamelike situations, into one great part of human reason: the learning of categories and concepts on the basis of an experience either wholly, or in some cases only partially, logically adequate to teach them. But neither the authors nor the reader will mistake the vast scope of the domain to which this research is relevant. "The research we have reported has mainly been drawn from the field of 'concept formation' so-called, but we would propose that our conclu-

sions are applicable to any phenomenon where an organism is faced with the task of identifying and placing events into classes on the basis of using certain criterial cues and ignoring others." Or again, very near the end,

> We have chosen to call this volume *A Study of Thinking*. A word in explanation of this title brings the enterprise to a close. Concept attainment is, to be sure, an aspect of what is conventionally called thinking, and in this sense the title justifies itself. But we have also urged a broader view: that virtually all cognitive activity involves and is dependent on the process of categorizing. More critical still, the act of categorizing derives from man's capacity to infer from sign to significate, and in so far as we have shed any light on categorizing as such it is our hope that we have also made clearer the nature of inference as a psychological phenomenon.

It is in passages like these that the authors point with firm hope to the future. With even greater frequency, they acknowledge their debt to their colleagues, present and past, and even to the "Zeitgeist," that has made it natural for psychologists to turn their attention to man as a rational being, and not only to the problems of his appetites, his folly, and his will.

How have the authors set about their enterprise? The main part of the book is divided into two principal sections: the first is primarily an analysis of categorizing activity, and its relations to general inference; and the discussion of the factors involved in learning how to sort the environment into functionally significant categories and equivalence classes. Here we find discussed the form in which decisions on how to learn occur in practice, how sequences of such decisions come to define a learning strategy, what general considerations may favor one or another course of learning, and how one may alter the weight of these considerations by changing the "problem." It is right that these descriptive and analytic chapters come first, before the discussion of the experimental material; the experiments could hardly be intelligible without this. Yet the authors themselves state that the clarity which illuminates these earlier chapters, and gives order and sense to the sequence of experiments, and meaning to the questions that they answer, emerged after long periods of observation and did not underlie the initial designs. ". . . the ideal strategies that have served us so steadily in this chapter are essentially refined versions of what we have observed our subjects doing. They were not invented by us in

an *a priori* manner. Our description of ideal strategies is a description of what, it seemed to us, our subjects were trying to 'bring off.'" Perhaps this also has to do with the hopeful quality of the book. If in these simple experiments, stylized as we have said and piteously artificial, enough could emerge to warrant an ordered review of so much of logic and of common sense, the experiments themselves take on an interest far greater than any single one of them reported in this, their summation.

Throughout the whole of the analytic discussion, and throughout most of the presentation of the experiments, the authors see, in the learning problems which they have studied, a very close analogy to the situations confronting the scientist when he plans his research program and tries to decide between alternative concepts and theories, which are at the moment still compatible with the evidence. Some parts of science are clearly not touched on in this—the moments of discovery, the times of creation. Here, rather, is the scientist doing his conscientious best, disentangling puzzles fairly well defined and finite. Indeed, it is the part of science which is most like a game that is closest to the situations dealt with in this study. The rules are well defined; the information is honest; there are no tricks: a world, to alter Einstein's "Raffiniert ist der Herr Gott, aber boshaft ist er nicht,"—in which God is not only not malicious but not even very subtle. But this, no doubt, is where most of us begin as children, and this, for sure, is where most of us still stay most of our time as men.

Chapters 4 to 7 describe the experimental designs, the experiments themselves, and the questions they raised; and chapter 8 returns to the summary of what has been learned, and to some of the principal questions raised to a new sharpness by the findings and their analysis, questions only partially answered or as yet wholly unanswered.

What do the experiments do? They are designed to make manifest the sequence of choices the subjects use in trying to learn. The verbal accounts the subjects give are occasionally referred to; they are not part of the experiment.

> In studying concept attainment, then, it has been our aim to externalize for observation as many of the decisions as could possibly be brought into the open in the hope that regularities in these decisions might provide the basis for making inferences about the processes involved in learning or attaining a concept. . . . To put the matter perhaps too simply, the analysis of performance strategy consists in comparing the actual performance of a subject with

> a set of rational or ideal strategies and determining a best fit. . . . In the study of thinking, inference, conceptualizing, and other such diversely labelled activities, the great technical problem is precisely this one. If behavior is to be viewed as strategy, the task of analysis can only be accomplished by devising experiments that can get a lot of sequentially linked behavior out of the organism where it can be observed.

The subjects of the experiments were students, mostly from Harvard, a few from Radcliffe. The number of subjects in one given experiment runs in the tens, seldom in the hundreds. The students are assigned a task of learning, usually from visual material, cards on which objects are printed or drawings, mostly abstract, some sketchily thematic. As far as the experimentor can arrange it, the world of the student is limited to these cards that he may see or select or be shown. The students are told that they are to learn about a class which contains some but not all of the cards. They are told whether the defining concepts are conjunctive (round and blue), or disjunctive (round or blue or both), and whether the relationship between the instance and the category is certain or only probable. Then the students are watched going about their learning. Sometimes there are limited opportunities for selecting instances, or for volunteering a solution; sometimes not. Sometimes the cards are presented with maximum order; sometimes not. Sometimes what is on the cards refers to a human world; sometimes not. What goes on is duly noted. On occasion, things which cannot be recorded as part of the experiment, such as an expression of pleasure at insight, or an evidence of mastery, are noted down as a problem for the future.

The four chapters on experiments, sometimes reviewing earlier work, but for the most part undertaken for the purposes of this study, are called, "Selection Strategies in Concept Attainment," "Reception Strategies in Concept Attainment," "On Disjunctive Concepts and Their Attainment," "On Categorizing with Probabilistic Cues."

We shall turn now to a sketchy and incomplete account of some of the findings. But before we do that, in order to stress again the abstract nature of the experiments, we quote the final sentences of this study, "We have idealized the experimental situations employed in our investigations beyond what is normal in daily life, but that is the price one pays for experimenting at all. It is our hope that by reaching a fuller understanding of these more idealized forms of thinking *in vitro*,

the complexities of thinking as we observe it around us will be more readily understood."

Huizinga, who sees human culture and man's rational life as an outgrowth of Homo Ludens, would, no doubt, concur.

A Study of Thinking is replete with findings based on experiments and their analysis. They are almost all statistical findings, in the sense that the traits of behavior discovered can not be predicated with universality and certainty of every subject. One of the findings, for instance, is that when students are trying to learn a disjunctive concept, they fare far better when their first instances are negative. This does not mean that every sequence started with a negative instance gives the quickest possible learning, nor does it mean that no subject whose first instance is positive learns quickly. But the statistical traits are striking, and strikingly different from a record of chance behavior; and in none of the important conclusions is there any question of their statistical significance. The samples are small, but they appear to be more than large enough. They are, however, quite specialized, and the question of whether Hindus, Senegalese, or Senators would behave like Harvard students is left over for the future.

The samples which are here briefly sketched seem typical to this reviewer in their interest, in their scope, and in the extent to which they seem to confirm, refute, or refine common sense views. I have attempted to select findings which could be presented with a minimum of specialized language, and this has caused me to omit many which are sharp and, to me, most illuminating. Even where no very specialized language is needed, we must remember that these refer to well-defined experimental situations, that they are in this sense objective, and in this sense limited.

A. It is possible, in the problem solving behavior of a subject, to identify a strategic pattern, and to get a measure of strategic consistency. ". . . it is possible to describe and evaluate strategies in a relatively systematic way, both in terms of their objectives and in terms of the steps taken to achieve these" . . . "Each of the strategies is amenable to relatively rigorous description, and it is fairly simple to employ a quite precise measure for describing the shift from one strategy to the other." Thus the authors indicate that they can usually identify a strategy from observation of the subject's choices and sequence of choices. It is all-important for the future of their work that

this identification be established as objective, in the sense that the criteria for identification can be learned by others.

The authors write further, ". . . it is possible to demonstrate the effect of relevant conditions upon measurable aspects of categorizing strategies. By so doing, we have been able to 'get into' the process of concept attainment. . . ." Subjects in general adopt strategies appropriate to the problem before them, the amount of information they are being given, and the instructions of the game. And then again, "In general we are struck by the notable flexibility and intelligence of our subjects in adapting their strategies to the information, capacity, and risk requirements we have imposed on them." If he expects to be allowed to continue, the student will take steps, the value of which lies in the future use of the information they yield. Some of the best strategies on purely logical grounds are unused because they require too much inference and too much thinking to be done readily in the head. Through all this, a strategy is a sequence of decisions made by the subject in an attempt to learn the concept. Through all this, the question of the relevance of education and culture comes often to mind. How universal are these traits?

B. A second set of findings has to do with a comparison between instances based on pictures, pictures of people that evoke stories and familiar scenes on the one hand, with pictures of shapes and figures of a neutral and abstract quality on the other. The thematic examples reduce the logical appropriateness of the strategies employed, and generally tend to lead to the testing of a series of hypotheses evoked by the themes. ". . . in attempting to differentiate exemplars from non-exemplars of a category, as one so frequently must in science, medicine, and indeed in daily life, the person will, in the absence of other information, tend to fall back on cues that in the past have seemed useful, whether these cues have been useful in an analagous situation or not." This is surely not the whole reason why the questions which most move and touch men are among the hardest to answer.

C. A third set of findings has to do with decisive evidence for the aversion and the ineptitude that are involved in the negative: in handling the negative instance, in learning from the indirect test, and in learning anything about disjunctive concepts. It is not that negative instances are not essential. They are in fact the principal instrument of correcting error and learning. But they are not liked and there is a marked "tendency on the part of subjects to *utilize only positive in-*

stances as a basis for forming hypotheses." Subjects also do not like to use indirect tests of a hypothesis. They do not like to have to transform negative information into positive information or a positive conclusion. Finally, subjects do not like and show little skill in attaining disjunctive concepts. The authors think that this may be a characteristic of our culture. "It is a characteristic of much scientific thinking to assume at the outset that whatever behaves in a common way does so for a common cause." This finding is clearly relevant to the problem of causality in history.

D. Strategies and the purposes of strategy are markedly affected, among many other things, by the extent to which the student can learn whether he is right or wrong. If he is told of his errors, he works hard to eliminate them and to solve the problem. If he has little opportunity to know whether he is right or wrong, he abandons this hope and adopts a prudential policy, keeping error within limited bounds. Such is our government.

E. In a beautiful little experiment on categorization of spoken sounds, the Harvard student regarded as distinctive sounds characterized by different letters in English. The mono-lingual Navajos, not Harvard students, categorized by the length of the vowel. Once the material was so arranged as to indicate the possible relevance of vowel length, English-speaking students categorized by it too. This is an example of a theme running through the whole book: powers of discrimination, unused but latent, are resurrected when evoked by the problem.

None of the findings sketched above, and indeed very few in the book as a whole, upsets what we would have expected, or outrages common sense; but in every case they suggest further studies; and in most cases, the questions to which they lead find no firm answer in common sense. This reviewer, at least, does not know the answers.

A Study of Thinking ranges through territory which has been for millennia a battleground of epistemology and metaphysics. It is thus not astonishing that from time to time the authors may be found temporarily manning one of the old trenches. Thus at one point they say, "To be sure, the defining criteria in terms of which equivalence classes are formed exist in nature as potentially discriminable." This does not keep them from writing, further on, "The categories in terms of which we group the events of the world around us are constructions or inventions. . . . They do not 'exist' in the environment." Nor is Dr. Brown able to avoid a bout with Locke and Berkeley. But the

authors' more steady view, it appears to me, they record as follows: "We have found it more meaningful to regard a concept as a network of sign-significate inferences by which one goes beyond a set of *observed* criterial properties exhibited by an object or event to the class identity of the object or event in question, and thence to additional inferences about other *unobserved* properties of the object or event."

That man must act in order to know, that he must thereby reject other actions of which he is capable, and lose other knowledge of what is knowable in the world, will not solve the old philosophical questions; but it will alter, deepen, and illuminate them.

NOW, GOD HELP THEE, POOR MONKEY!*

By CHARLES TOMLINSON

Mr. Coveney's study of the child in literature (its title comes from the words of Lady Macduff to her son) is typical of a good deal of the critical writing that appears in England at the present. At its best level, his book is highly informative and stimulating. At its average level it seems uncertain of the nature of the audience it has to deal with, and consequently disperses much of its force in retailing background information of the kind that the educated reader already possesses. At its worst level *Poor Monkey* is somewhat derivative in substance and tired in tone. Now this is a pity. For the book possesses a real core and its materials are potentially and, at times, actually a valuable addition to our notions about literature.

The author traces the passage of the literary image of the child from Blake to Lawrence. He sees in the Romantic use of that image a creative symbol, "a focal point of contact," as he says, "between the growing human consciousness and the 'experience' of an alien world." In short, the child focuses a disquiet and, at the same time, the artist's hopes for human salvation: it is a touchstone for life. The corruption of that symbol provides Mr. Coveney with matter for some of his most interesting and original chapters; the symbol of growth gives place to its antithesis, to the Victorian image of the "dying child" and to the

**Poor Monkey: The Child in Literature.* By Peter Coveney. London: Rockcliff. 30s.